# CK, AN ENGINEERING DESIGN THEORY?

Denis Choulier, Eric Coateana, Joelle Forest

## To cite this version:

Denis Choulier, Eric Coateana, Joelle Forest. CK, AN ENGINEERING DESIGN THEORY?: CONTRIBUTIONS, LIMITS AND PROPOSALS. International Conference on Engineering Design ICED 2011, Aug 2011, Copenhague, Denmark. pp.323-333. halshs-00705387

## HAL Id: halshs-00705387
## https://shs.hal.science/halshs-00705387

Submitted on 7 Nov 2014

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

**INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED11**
15 - 18 AUGUST 2011, TECHNICAL UNIVERSITY OF DENMARK

# CK, AN ENGINEERING DESIGN THEORY? CONTRIBUTIONS, LIMITS AND PROPOSALS

To cite this version:
Choulier Denis, Coatanéa Eric, Forest Joelle, CK, an engineering design theory? Contributions, limits and proposals, Proceedings of the 18th International Conference on Engineering Design (ICED, 2011), Impacting Société through Enginering design, Vol 2: Design Theory and Research Methodology, pp. 323-333.

## ABSTRACT

The CK theory developed by Hatchuel, Weil and Le Masson has raised interest and controversies in the academic and practitioners' communities. This paper is participating to this debate. After presenting the scope, focus, and the contributions claimed by its creators; the authors analyse the interest of considering also other concepts and models usually integrated in traditional design knowledge and practices. Indeed, it can be noticed that important concepts such as the concepts of function and structure for example seems to remain outside the perimeter of CK even if some of them are integrated in the research programs of the authors. This is not a central limitation if the real scope of the theory will be minimized, compared with the initial ambition of the CK's creators. It is nevertheless a fruitful contribution which explicitly creates a distinction between knowledge, concepts and notes the importance of *expanding partition*. The present contribution proposes to enrich the initial scope of CK by integrating theoretical contributions made by other authors and by considering concepts widely used and accepted in engineering design.

*Keywords: Engineering Design, design theories, CK theory*

## 1 INTRODUCTION

During the past two decades, the increasing economic competition and the increasing pressure on traditional and new industries have created problems that are putting into treats entire economic sectors into several countries. This evolution due mainly to the evolution of the economic paradigm and economic dogma has emphasized much more than before the importance of innovations as a key parameter for the survival and renaissance of several industrial sectors.
At the same time researches, initiated by S. Kline and N. Rosenberg in their *Chain*-Linked *model* (1986), following the perspective initiated by Herbert Simon [16], showed that in order to improve innovation ability, we must take into account the design process. This hypothesis has gradually led to the development of design theories able to explain and direct innovation processes and strategies. The CK theory is one of the numerous attempts made to address this challenging scientific issue.
The present article aims at analyzing this specific theory and is organized in the following manner.
First, in section 2, the article presents the scope and focus of the CK theory. Then, the authors of this article develop propositions based on comparative studies of the concepts used in CK theory with some existing concepts, tools and theories that have been developed before in design science. Section 3, is proposing to consider the dimension of interactivity in creative processes. Interactivity should be considered here to have the sense of external propositions interacting with the designer. In section 4, the article is questioning CK relatively to its real link and efficiency in engineering design. Section 5 is concluding the present contribution and is opening other research questions that can lead to further developments.

## 2 A SURVEY OF CK THEORY AND CLAIMS

The present section aims at presenting and summarizing the key concepts of the CK theory. Before presenting them, it is however necessary to understand the purpose and scope of such a theory.

### 2.1 Purpose and scope of the CK theory

Le Masson, Weil and Hatchuel position their work in the RID model where R stands for Research, I for Innovation and D for Development [2].

According to them, D is defined as a controlled process which activates existing competences and knowledge in order to specify an artefact which should satisfy some well known objectives. In such a viewpoint, the development process aims at instantiating parameters; these parameters being fixed ex ante by a generative model. Thus, the extend in which D can support the exploration of new alternatives in not independent from the generative model on which the development process is based. Then the result of the development process is strongly dependent from the initial conditions defined by the generative model.

Research is defined as a process which provides scientifically controlled knowledge needed for D.

However, neither R nor D can initiate a design process concerning ill-defined objects. It is precisely the goal of the function I which is dedicated to the co-evolution of competencies and products.

If we accept such a viewpoint, arises the question of knowing how to organize I?

In order to answer to this question they develop a model of collective action on I based on an innovative design reasoning approach. They suggest that CK is the original formalism of the design reasoning used in I.

Their research program aims at:

- Defining a design reasoning based on the functional logic (the concept of functional logic is presented as leading to an interpretation using the concept of function), the expandability of the knowledge and the expandability of the propositions.
- Establishing the conditions allowing such type of reasoning,
- Defining the main operators allowing such type of reasoning,
- Deriving more general consequences from the theory.

### 2.2 Concepts and operators of CK theory

They define design as [11] (p.124): “assuming a space of concepts C and a space of knowledge K**,** we define Design as the process by which a concept generates other concepts or is transformed into knowledge, i.e. propositions in K”

Knowledge is a proposal having a logical status for the designer or for the customer (True or False in binary logic, but the type of logic do not matter really). On the contrary, a concept is defined as a notion or proposition without any logical status: It can not be said from a concept whether the concept by itself is right or wrong” [3] (p. 123-124). “Space C is the space of concepts. Concepts are undecidable propositions in K (neither true nor false in K) about some partially unknown objects x.”[3].

According to the authors, the design reasoning can be theorized as the co-evolution of these two spaces C and K. They call "capacity of expansion" the ability of the design process to generate novelty via a reasoning which begins by a disjunction $K\rightarrow C$ which is creating a concept and ends by a conjunction $C\rightarrow K$ transforming a concept into knowledge.

They defined the operators (C-C, C-K, K-C, K-K) which organize the co-evolution of the C and K spaces in the following manner [2]:

$K\rightarrow C$: This operator adds or subtracts to concepts in C some properties coming from K. It creates “disjunctions” when it transforms elements from K into a concept. This also corresponds to what is usually called the “generation of alternatives”. Yet, concepts are not alternatives but potential “seeds” for alternatives. This operator expands the space C with elements coming from K: concepts cannot be imagined without knowledge. They call this **K-relativity** of a design process [3].

$C\rightarrow K$: This operator seeks for properties in K that could be added or subtracted to reach propositions with a logical status; it creates conjunctions which could be accepted as “finished designs” – when true. Practically, it corresponds to validation tools or methods in classical design: consulting an expert, doing a test, an experimental plan, a prototype, a mock-up are common examples of CK operators.

A design solution is precisely what Hatchuel and Weil call a "conjunction". They have reached a concept which is characterized by a sufficient number of propositions that can be established as true or false in K.[11]

K→ K: This operator allows a knowledge space to have a self- expansion. This operator corresponds to an expansion of the knowledge space obtained by deduction and/or experiment. This operator is not fundamental for the design process to occur. This operator and the following one are corresponding to the exploration of the design space.

C→C: Finally, the operator C→C explains the expansion of the concepts space. The expansion of C (the addition of a new concept) can be done by removing a property to a concept, it is then an inclusion. Adding a property constitutes otherwise a partition. The partition is a restricting one if the property already belongs to the concept. It is an expanding one in the case where a new property is added to the concept.

These mechanisms make the C space a tree structure (partitions correspond to the creation of new "branches", inclusions to their pruning). We can only create new concepts (new sets) by adding or subtracting new properties to the initial concept.

As a summary, for the CK authors' the mechanism of expanding partition is the elementary motor of design (on the contrary of the approaches of problem solving). The mechanism of expanding partitions requires therefore two initial conditions:

- The set to partition is not completely specified. This set is expandable.
- The partition is activated using an external knowledge, outside of the CK-space.

CK authors consider that their model "clarifies the oddness of Design reasoning. There is no design if there are no concepts: "concepts are candidates to be transformed into propositions of K but are not themselves elements of K." and they justify this definition by developing an argument already developed before by Tomiyama and Yoshikawa in their General Design Theory [23]: **"**If the proposition is true in K it would mean that this entity already exists and that we know all that we need it (including its feasibility) to assess the required properties. Design would immediately stop!"[11]. They claim that a false proposition in K will also result in stopping the design.

## 2.3 Critical claims and some limits

CK appears as a very high level theory with both fundamental mathematical roots and applicative consequences. The major claims of the CK's authors are:

1. The preservation of the consistency of definitions in K can be explained by Forcing [8], a method of Set theory developed by Paul Cohen in 1963 for the "invention" of new sets.
2. The links between design and knowledge are clarified and draw fundamental interdependences. Without concepts, no novel knowledge is possible and without prior knowledge, no concepts can emerge, otherwise how to make disjunctions. There is no autonomous theory of knowledge
3. The design theory CK allows distinguishing two extreme forms of innovation: the conceptual innovations (great conceptual expansion without significant expansion of knowledge) and erroneously named applicative innovation (a great expansion of knowledge without much conceptual expansion). Hatchuel and Weil agree with the viewpoint of Kryssanov, Tamaki and Kitamura [14] who some years earlier claimed that a "theory of creativity is a theory of transformation of the space of concepts" [21].
4. CK-theory is a tool to direct and organize the innovation process [2] [4][8]. They claim that they can combine the possibility to control innovation process and at the same time to develop creativity by creating new islands of knowledge in the exploration phase of K.

Nevertheless, some limits of CK, can be pointed out. In a previous paper [33], some of them have been highlighted.

Among them, three will not be developed in this article. One is a very fundamental critic concerning the falsifiability of CK – in other words, can CK be considered as a scientific, testable, theory?

The second concerns hypothesis made for the construction of the two spaces. For the K space, no structure appears necessary for the concepts development. For the C space, the assumption of a tree structure is too restrictive for encompassing all the possible operations leading to concept developments.

The third limit is the absence of any criteria allowing the designer to decide on the next action to be taken at a given time. For instance, which property or property type to introduce into a concept? Should the designer prefer an inclusion, a restricting partition, an expanding one, or force a conjunction? Without such criteria, the claim of the creators of the theory to guide the process is abusive. Other critics will now lead us to propose directions for possible improvement or adaptation of CK in the next sections.

# 3 Interaction with an external world?

The interaction with the "external world" will refer to dimensions of the design situation that surround the reasoning with propositions. It has a similar meaning than in [25]. Interactivity is not explicitly considered in CK. Nevertheless, these dimensions of creative processes cannot be forgotten.

## 3.1 Expandable rationality versus bounded rationality

Expandable rationality refers to the time and constraints due to the limited resources a designer must account for. No creative process occurs with unlimited resources. We must refer here to the seminal work of Simon [16].

Hatchuel and his colleagues argue that the CK theory allows to "make operational the concept of *expandable rationality* which is opposite to the one of *bounded rationality* (...) Indeed, the common vision of *bounded rationality* seems to enclose the rational reasoning in a space of constraints which delimits the rational reasoning strongly" [3]. This argument is however one possible misunderstanding of the concept of Simon, who does not consider knowledge, but the cognitive cost of action.

Simon's interest was in human decision-making and problem-solving processes. He observed that decisions are not made the way standard theory suggests, that is to say to choose rationally a solution among existing alternatives, following well-defined criteria, and applying “substantive rationality” principles.

He presented the rationality of action from the decision making process leading to action. He therefore also rejected the idea of the omniscient decision maker (homo œconomicus) and promoted the concept of bounded rationality.

The aim of Simon’s concept of bounded rationality is not to show that individuals or organizations are irrational in their assessments and decision making processes. In fact, it underlines the cognitive constraints the designer has to cope with. Considering the bounded rationality [17] [18] means recognizing that even if the entire set of possible actions is theoretically given, it is not given in the practical sense because of the practical limitations of our computing resources (processing) to generate all possible actions and to compare them.

Simon characterizes bounded rationality more positively and formally by the concepts of “search” and “satisficing”. His main idea is based on the “heuristic search hypothesis”, which stands that “problems are solved […] by searching selectively (i.e. heuristically) through a problem space (i.e. a problem representation)” [19]. The designer begins with the recognition of a need for acting: create a new artefact that should satisfy a need or improve its satisfaction. The “search” for alternatives is initiated when the designer generates solutions. Lastly, a “stop rule” is required to end this costly cognitive process. If alternatives cannot be found that are satisfying, then satisfaction levels will drop until an alternative is found [20]. This last point leads Simon to conclude that “Designing is satisfying if finding an acceptable solution” [19], which is more “reasonable” or satisfactory, than optimal in the sense of the rational choice theory.

So, the so-called opposition between expandable rationality and bounded rationality is only apparent. It seems difficult for CK theory to occult the limits of the human rationality. The C expansion underlined by Hatchuel and Weil must be a bounded process.

By taking into account the bounded rationality, we focus on the impossibility for an infinite expansion of the concepts (due to the inability to treat all information that arises, because of the limitations of cognitive abilities). Added to the fact that CK do not propose criteria for deciding an action, this inevitably questions the way the process is piloted by designers.

Then given the speed of production and codification of knowledge that characterize modern economies, today this is the attention, not the knowledge which became the scarce resource [21] (p.25). This question is not treated in CK theory.

### 3.2 But design is also a social process!

Extending the CK theory by integrating the bounded rationality is not sufficient because, we remain centred on the design reasoning. The design reasoning masks the crucial question of the social dimension of the design process.
Indeed, if Hatchuel et Weil [2] [4] assert that design is not only a mode of reasoning, one must note that they only considered the theory from the design reasoning perspective without considering explicitly the work division aspects and the evolution of organizational principles in design. This might be due to the fact that by focusing their attention on the reasoning aspects they have under estimated the importance of the social dimension in design.
Indeed, in CK theory, innovative design is considered and analyzed at the designer level, and more precisely at the designer reasoning level. However, can a theory of design, which presents itself as a unified design theory, can forget the collective dimension of design activity?
Considering the collective dimension of design raises the questions of the knowledge that designers bring to K space, the variety of their knowledge since resource heterogeneity provides a clear potential for creativity, and the cognitive distance between actors which determine their ability to cooperate effectively during the design reasoning. Moreover, the problems of cognitive costs are intensified in situation of collaborative design and/or distributed design. Cognitive synchronization of the different actors takes time and resources, and organizational aspects are fundamental.

We also need a theory of design which goes far beyond the design reasoning and takes into account the cultural and historical dimension too. This is due to the fact that cultural and historical dimensions are determining strongly the possibility of design expansion. For example, Simonton [22], considering long periods of time, showed statistical correlations between the creativity level and the following parameters: the type of society (democratic versus autocratic), the political context (War…), or the economic one (Crisis, financial disposal, number of competitors). The same type of correlation might be probably established with the level of alphabetization and later with the level of education of populations and societies.

### 3.3 Design is also made of representations

In many works, design is described as an activity based on the use of product representations: drawings, diagrams, models, mock-ups, numerical representations such as CAD, virtual reality representations.
The cognitive work done by designers to move from physical or numerical media to mental representations is important in design cognition.
Fundamental issues concern the way designers can express and develop they ideas through the use of representations, and representations tools.
This point is certainly not critical, since many other design models, and nearly all the engineering models of designing, never consider representations and their linkage with reasoning. Moreover, an article of Tsoukias & Kazakci considers such a linkage from the concepts of the cognitive worlds of J. Gero [25]. Their article points out that the design process can progress only if we introduce a third element that they name the external representation of C and K space. Tsoukias & Kazakci claims that "the external representations and their reinterpretations are the main engines through which the design process progresses". Design representation and the designers are external entities to the object to be designed. They are situated in its environment and the environment should be represented in order to allow the acquisition of knowledge. The central role played by the environment is also pointed out in the work of Zeng et al. [27]
As already mentioned, the human dimension is absent from the CK theory because this dimension in the theory is reduced to the reasoning aspects.
This part shows that CK theory mainly seen as a theory for creative reasoning can beneficially take benefit of other concepts in order to form an effective and an applicable theory for creativity. This aspect is developed in the following sections.

## 4 CK and engineering design?

There are many works on the design process, largely developed in Germany, USA or Japan, in particular the Systematic Design or the General Design Theory. Although these works are well known and quoted [13] [15] [23], the authors of CK theory do not include in their theory several of the theoretical concepts used and introduced in these approaches. This is especially the case for the "duality" between Functions and Structure; and for the concept of process itself, which, for engineering design, refers to relatively well identified phases. The description, distinction and selection of concept solutions are also other aspects not considered in the CK theory. Another aspect not considered in the CK theory is the description of the environment of a product or service. This aspect is seldom considered in an explicit manner in traditional design theories. But design is a human activity that aims to change an existing environment to a desired one by creating a new artefact into the existing environment. The Environment-Based Design (EBD) is such a design theory that studies and supports this environment change process. The underlying principles behind the EBD are that design comes from the environment, serves for the environment, and goes back to the environment [27].

Nevertheless, the authors of the CK theory have during the past years probably noticed some of the limitations of their approach and have tried to more carefully define the scope of CK. In 2 they claim that CK is a theory of the creative reasoning mobilized in design [2] (p.282). More precisely as described in section 2.1, they make a clear distinction between Research, Innovation and Development and claim that the creative reasoning is taking place in R and I. D is defined by them “as a controlled process which activates existing competences and knowledge in order to specify an artifact which should satisfy some well known objectives. In such a viewpoint, the development process aims at instantiating parameters; these parameters being fixed ex ante by a generative model."

This perspective is considering that the “generative model” is not resulting from the phase D (Development). This is probably a misunderstanding of the importance of phases such as the embodiment and detailed design phases.

### 4.1 Functions, structure, and CK operators.

All the models and theories in engineering design more or less consider engineering products from –at least- two viewpoints: structure, and functions. When expressing the structural characteristics of a product, a designer establishes a nomenclature of components (i.e. types of, references…), a product architecture (links between components, topology, contacts…) and, for each component the descriptors of its forms, dimensions, and matter. The functions of a product relate to the actions between components, and between the system and its environment, but also with the flows of matter, energy and information. There are several possible definitions for the concepts of function, behaviour, and need; but the most important point is that the relations between structure and functions are of deduction type. The structural parameters condition the functions and design rules can take the form "IF structure, THEN function": The effective functions are consequences of the structure (deduction). However, the structure is a condition sufficient for the effective functions, but a condition among others (abduction).

According to the recursive logic of design [28], at most stages of (conceptual) design, an evaluation operation will be determined only after a (partial) design solution is generated, which will in turn trigger new synthesis operation. As a result, design is a nonlinear process where a small change in the initial design problem may give rise to significant differences in the final design solutions, among which creative design solutions may exist [29] [30] [31]. According to the recursive vision of the design process both functions and structure are participating to the design process and cannot be separated, in the same way it is very difficult to see what is coming first the function or the structure because both of these concepts require the presence of the other in order to be thought.

CK forgets this fundamental dichotomy of design between the means and the goals, or, expressed with an engineering language, the importance of the relations built during designing between structure and functions. Probably this omission can be seen as a condition to consider CK as a higher level theory able to describe not only creative design reasoning, but creative reasoning including design. But to accept such an argument, one should accept either to see design as an instance of creativity (design included in creativity), or to consider the part of creativity inside design as an independent component of design - one could model with a higher level theory. This is not our position: design includes some creativity but is not limited to it; and creativity can hardly be detached from the other sub activities that make design.

In this section, the objective is not to improve CK, nor to confront or position it relatively to engineering design, but to question what CK concepts could bring to our comprehension of design processes. Especially, the operations of concept expansions (inclusion, and partitions - expanding and restricting) form a very interesting typology, which we propose to keep, specify, and even develop, with regards to functions and structure. Reversely, this attempt of reconciliation of some concepts of CK with the function/structure co-evolution will question the concepts of knowledge, the expansion operations in C and their relations to knowledge.

**Knowledge**

For CK, the considered propositions take forms such as "There exists an object having the property P1, P2, …". By introducing two types of entities, we define two types of elementary propositions, on the structural parameters, and on the functional one:

- "There exists an object having a structural characteristic (or parameter) S"
- "There exists an object having a function F"

But this first typology proves to be incomplete. First, it forgets knowledge on the existing links between structure and function: the rules. Second, such elementary propositions are not sufficient to contribute to a capacity of action for an activity whose fundamental objective is the building of links between functions and structure. Rules must also be formulated in CK terms. Such a formulation could be: "There exists an object for which the structural characteristic S (or several characteristics) conditions the function F (or several functions) ". But one can propose more operational rules such as "There exists a product for which the modification (withdrawal, introduction, quantitative change…) of the structural parameter S leads to a modification (idem) of a functional parameter F". When such knowledge is introduced into C, it will automatically lead to the definition of new parameters, basically those related to the new concept (whereas in the theory CK, pieces of knowledge seem to be independent from/to each other).

**Expansions in C**

The following expansion operations will then be considered.

- The addition to an existing concept having a structural property S of a functional property F linked in K to the structural property S. This is as an addition of a property, therefore a partition, but this is necessarily a restricting partition since F is basically linked to S (in K).
- The addition to an existing concept having a functional property F of a structural property S linked in K to the property F. This is also an addition of a property, and a restricting partition (F is basically related to S), but contrarily to the previous case, this new structural property indicates a possibility; it is not a consequence. The property S could later be removed without removing F, and replaced by another S' property (generation of an alternative structure).
- The addition or modification of a new property (either structural or functional), nonrelated to a property of the initial concept. This is an expanding partition.
- The withdrawal of a property P of a concept but this withdrawal will necessarily engage on a questioning concerning the properties which are linked to it in K. A decision to keep or delete them should therefore be taken. This is an inclusion.

Among these expansion operations, the two firsts contribute more to the development of a concept than to a "pure" creation. But the "development" has a different meaning than the term D in the RID model of Le Masson, Weil and Hatchuel [2] and refers more to the recursive logic mentioned above [28]. By contrast, expanding partitions will have as a consequence the proposal of a concept having a radically new property (without links to the other properties of the concept when the concept is generated). But now the question is whether such a concept can – or not – be considered as a (partial) design solution.

**Two key comments**

First comment, the concept of restricting partition: As defined in CK, a partition is the addition of a property to a concept, and it is restricting when this property "already belongs to the concept C". The last part of this sentence must obviously be interpreted since one cannot add to C what already belongs

to C. But one can at a given instant define it or take it into account - to integrate in the definition of a new concept. Restricting partitions should moreover be defined as the addition to a concept of a property already linked in K to a property of the concept (but this new property does not "belong" to the initial concept): this is our definition of a restricting partition.
The second comment comes from the definition of an innovation by the authors of CK. Innovations are supposed to result from expanding partitions, and only from them. However, it is not clear whether a succession of restricting partitions such as defined above could also, without any expanding one, lead to the definition of a new concept. Or, can the use of recursive logic lead to innovation? This can especially be the case for innovative solutions to technical problem considered in TRIZ or ASIT. We think that it would be appropriate to extend the CK definition of an "innovation", or at least to no more consider expanding partitions as the unique source of innovations.
Operations from K to C must therefore be considered in different ways for the design process. While taking part to what we called the development of a concept (leading to the proposition of a product definition, but not still evaluated), the restricting partitions made by designers, not necessarily foreseeable, will gradually attach new properties to existing ones, by successive cycles made of deductions (S→ new F) and abductions (F→ new S) - recursivity. They will mobilize knowledge on the rules, extracted from K; obviously K→ C operations. In contrast, the possibility for designers to add at any time radically new properties, not linked in K to a property of the initial concept is an expanding partition. Examples can be additions or modifications of requirements, or radically new structural propositions. But such expanding partitions refer more to framing or reframing [34]. And framing is not the core of engineering design. With other terms, we established here the difference between the proposition of a radically new feature (framing or expanding partition), and the building of a solution from this first introduction. This difference is also discussed with other terms in [35].

**Concepts**
The development of a concept mobilizes elements of knowledge from K. The question of the end of the development of a concept is posed. Are there conditions (and which ones) to allow a designer to consider that a concept is sufficiently developed?
Such a question is addressed in GDT for example.
With CK terms, which are the conditions for a conjunction? We recall that, in a practical way, conjunctions correspond to the use of evaluation tools or methods such as consulting an expert, doing a test, an experimental plan, a prototype or mock-up.
Obviously, a concept which would not comprise at the same time structural properties and functional properties could not lead to a conjunction. The first (no S) cannot be tested. The second (no F), would not allow to specify which property to test. One can then define two types of concepts.
A "complete" or "developed" concept has the following elements: It includes in its definition Structural as well as Functional parameters. The links between S and F (rules – deduction) are established, and to any F corresponds at least a link with a S. This definition corresponds to a "solution" [35]. Such a concept can be tested – even if the designer can always choose to continue to develop it, or to make an expanding partition. In this sense CK is regarded as a purely descriptive theory.
Elsewhere an "incomplete" concept does not verify at least one of these conditions. The designer will necessarily have to expand it - with “restricting partitions”.

## 4.2 CK in the design process.

The place of CK in the design process should now be addressed. CK appears to be usable very early in the innovation process since it concerns concept generation. New concepts seems close to new products, and the examples given in CK papers are nearly systematically examples where new functions or/and new uses are put together in a sort of functional synthesis sometimes leading to radical functional shifts (e.g. from the initial need to develop a new smart shopping cart, the result is either a proposition to develop new interfaces between the user and the supermarket, or a redesign of a smart supermarket [10]).

Above, we demonstrated that there is a significant amount of steps in the design process to consider between the addition of a new property (e.g. an expanding partition) and a "ready to test" concept. CK considers some very initial aspects of the design process but do not describe “a ready to test” concept in a sufficiently precise manner. In the initial part of the design process restricting partitions play a central role. One could even think that restricting partitions are the operations that allow the design product to be built. One could imagine designing without expanding partitions, but certainly not without restricting ones; whereas CK moreover focuses on the role of expanding partitions.

But a "ready to test" concept does not mean a good concept. Until now, the operations were mainly mental ones. It is now time to confront the product to the real world. This confrontation is described by CK operators, since it corresponds to a conjunction, followed by either new concept generations when the conjunction fails to give a new knowledge (a true proposition – a product definition); or by the end of "design". Nevertheless, this part of design is poorly described regarding its importance and frequency in a design process. Situations where tests (conjunctions) lead to the discovery of new product features are common. Designers also currently discover new problems – emergent, connected, resulting. And there are differences between solutions locally satisfying and a satisfying global solution – the complexity of product definition during design is not addressed in CK. The process leading to the definition and validation of operating principles for a product (conceptual design phase) often goes through sequences of problem solving and problem emergences. No doubt that this recursive process also contribute to design creativity. Some theory of design [28] claims that the recursive process is playing a central role in the design creativity. For this reason the initial conditions and description of a design problem is a central aspect that condition heavily the final design outcome. Regarding this aspect, CK is not providing the necessary concepts needed to diminish the initial ambiguity of the design problem description.
Further, the downstream steps such as embodiment and detailed design are also not discussed in the theory. During those phases, problems appear and have to be solved, also involving some form of creativity.

There is probably here a difficulty due to the definition of the scope of design, but also due to the definition of creativity. For engineering, if we commonly agree that design involves creativity, we also consider that the engineering design process ends with a complete description of a satisfying product. There is a long way from an expanding partition to a "ready to test" concept. But there is a much longer way from a satisfying concept to the end of the conceptual design phase. And still, the design process is not finished and could also involve creativity during embodiment and detailed phases.
The difficulty is not that CK cannot describe those phases – it can in certain extend. But these complex aspects have never been explicitly highlighted by the authors of the theory. Instead, the accent is put on small operations that occur during a small part of the conceptual design phase; whereas creativity (e.g. in a broader sense: problem solving but also problem finding, problem analysing, and problem management) is necessary during all the phases of the product design.

# 5 Conclusion

After having written a first paper where we critically examined CK claims, we intended to make two propositions in order to better take benefit of some fruitful concepts introduced by the theory. We have tried to focus more specifically on the engineering design process.
In the first one, we consider that CK could be complemented with considerations relative to the limited rationality of persons, but also to the social dimension of creativity and to the use of representations. Such a concern appears important in order to give account for the multiple dimensions of creative processes, which are not limited to "pure" reasoning.
In the second proposition, we consider CK concepts as elements that can usefully highlight the engineering design process. CK is contrasted with the classical notions of functions and structure and gives means to discuss and better define the creative aspect of design. Nevertheless, because CK is mainly focused on the introduction of new properties, CK cannot encompass the complexity – and richness - of design.
There are finally two possible positions for the way in which one can see CK.
The first approach is to see it as a theory of design. But as defined by its authors, it appears disconnected from the other models and usual concepts in engineering design, and its operational character is questioned. In order to expand its scope to engineering design, we tried to introduce missing but fundamental elements: the fundamental distinction between structure and function, the recursive aspect of design, the need for stop rules and evaluation processes.

With these adjunctions, we can use CK concepts to interpret engineering design. Operations defined in the theory, but also the definitions (concepts, knowledge), are then clarified. Another aspect not treated by CK and essential for the development of an engineering perspective is the comparison and evaluation part. This aspect has been extensively developed in other theoretical developments such as the extended GDT theory [23]. This aspect will require developing an analysing the role played by describing attributes of a problem or a solution. Several works [32] have tried to develop further the analysis of this other fundamental aspect of engineering design.

The second vision of the CK theory would be to keep the initial framework of CK and not trying to consider anymore the explicit distinction between functions and structure. In this perspective CK cannot be considered to really be a design theory. CK is then mainly a descriptive tool that can be used for tracing certain aspects of the design process. Nevertheless, CK in this initial form can be useful to analyse and record some of the elements involved in the creativity process such as the ability of designers to combine knowledge and concepts. The operators developed in CK can support the creativity analysis process but more of them should be considered. They have been developed in the inferential design theory [12] [13] and provide most probably a more extensive framework to analyze the synthesis aspects of the creativity process. An extension of CK to dimensions such as the limited rationality, social perspectives, and the use of representations is also possible.

**Acknowledgments**

The work reported in this paper by ? was funded under by the Multidisciplinary Institute of Digitalization (MIDE) of Aalto University, project HYBLAB.

**References**

1. Hatchuel, A. and Weil, B. (2002), *La théorie CK, Fondements et usages d'une théorie unifiée de la conception*, Proceedings of The Sciences of Design : The Scientific Challenge for the 21st Century In Honour of Herbert Simon, 15-16, march, Lyon.
2. Le Masson, P., Weil, B.and. Hatchuel, A. (2006), *Les processus d'innovation : conception innovante et croissance des entreprises*, Hermes, Lavoisier.
3. Hatchuel, A. and Weil, B. (2008), *Entre concepts et connaissances : éléments d'une théorie de la conception*, pp. 115-131, in A. Hatchuel et B. Weil (eds), Les nouveaux régimes de la conception : langages, théories, métiers, Cerisy, Vuibert.
4. Hatchuel., A. and Weil., B. (2009), *CK design theory: an advanced formulation*, Res Eng Design (2009) 19:181–19.
5. Hatchuel. A., Le Masson P. and Weil B. (2004), *CK theory in practice: Lessons from industrial applications*, Design 2004 ( Dubrovnik),
6. Tsoukias A. and Kazakci O.A. (2004), *Extending the CK theory: a theoretical background for personal design assistants*, ,Design 2004
7. Kazakçi O.A., Tsoukias A. (2005), *Extending CK theory: a theoretical background for personal assistants*, Journal of Engineering Design, 16, 4 p.399-411.
8. Hatchuel, A. and Weil, B. (2007), *Design as Forcing: deepening the foundations of CK theory*, ICED 07, Abstract p 325-326.
9. Le Masson, P., Weil, B.and. Hatchuel, A. (2007), *Creativity and design reasoning: how CK theory can enhance creative design*, International Conference on Engineering Design, ICED'07
10. Le Masson, P., Weil, B.and. Hatchuel, A. (2008), *Teaching innovative design reasoning : how could CK theory help?*, Int Conf on Engineering Design, 4–5 Sept 2008, Barcelona
11. Hatchuel, A. and Weil, B. (2003), *A new approach of innovative design: An introduction to CK theory*, ICED 03 Stockholm, August 19-21, 2003.
12. Ryszard, S. and Michalski (1993), *The Interencial Theory of Learning: Developing Foundations for Multistrategy Learning*, In Machine Learning: A Multistrategy Approach, Volume 4, R.S. Michalski & G. Tecuci (Eds.), Morgan Kaufmann Publishers.
13. Arciszewski T. (1994), *Inferential Design theory: A conceptual outline*, Machine Learning and Inference Laboratory, George Mason University.
14. Kryssanov, V., Tamaki, H. and Kitamura, S. (2001), *Understanding design fundamentals : how synthesis and anlysis drive creativity, resulting in emergence*, Artificial Intelligence in engineering, vol 15, Issue 4, October, pp. 329-342.
15. Pahl G., Beitz W., *Engineering design: a systematic approach*, London: Springer, 1984.
16. Simon, H.A. (1955), *A behavioral model of rational choice* , Quarterly Journal of economics, 69, pp. 99-118.
17. Simon, H.A. (1976), *From substantive to procedural rationality*, S. Latsis (ed.), Method and Appraisal in Economics, Cambridge University Press, Cambridge (MA).

18. Simon, H.A. (1995), *Problem Forming, Problem Finding and Problem Solving in Design*, In: Collen A, Gasparski W.W (Eds.), *Design and system, Praxiology*. New York, NY, Transaction Publishers.
19. Simon, H.A. (1992), *Methodological Foundations of Economics*. In : Auspitz J.L., Gasparski W.W., Mlicki M.M., Szaniawski K. (Eds.), *Praxiologics and the philosophy of economics*. New York, NY, Transaction Publishers, 25-41.
20. Amin, A. and Cohendet, P. (2004), *Architectures of knowledge : Firms, capabilities, and Communities*, Oxford University Press, Oxford.
21. Simonton, D.K. (1975), *Sociocultural context of individual creativity: A transhistorical time-series analysis*, Journal of Personality and Social Psychology, Vol 32(6), pp. 1119-1133.
22. Ahmed S., *Understanding the use and reuse of experience in engineering design*, PhD Thesis, Cambridge University Engineering Department, 2000.
23. Tomiyama T. and Yoshikawa H. , *Extended General Design Theory*, in H. Yoshikawa and E.A. Warman (eds.), Design Theory for CAD, pp. 95–130, North-Holland, Amsterdam,1987.
24. Otto K., Wood K., Product Design: Techniques in reverse engineering and new product development, Prentice Hall, 2001.
25. Gero J. S., Kannengiesser U., *The situated Function Behaviour framework*, Design Studies Vol 25 N°4 pp 373 - 392, 1st publication in Artificial intelligence in design 02, J S Gero editor, Kluwer academic publishers, 2002, Isbn 1-4020-0716-7, 2004.
26. Altshuller G., *Creativity as an exact science*, Gordon & Breach, Luxembourg, 1984.
27. Zeng Y., *Environment-based formulation of design problem*, Transactions of the SDPS: Journal of Integrated Design and Process Science, Vol. 8, No. 4, pp. 45-63, 2004.
28. Zeng Y. and Cheng G., , On the logic of design, Design Studies, Vol.12, No.3, pp.137-141, 1991
29. Cheng G. and Zeng, Y., *Strategies for automatic finite element modeling*, Computers and Structures, Vol. 44, No. 4, pp. 905-909, 1992,.
30. Gu P., Zhang X., Zeng Y., and Fergerson B., *Quality analysis and optimization of solid ground curing process*, SME Journal of Manufacturing Systems, Vol. 20, No. 4, pp. 250-263, 2001.
31. Zeng Y., Pardasani A., Antunes, H., Li, Z. Dickinson, J., Gupta V., and Baulier,D. *Mathematical foundation for modeling conceptual design sketches*, ASME Transactions: Journal of Computing and Information Sciences in Engineering, Vol. 4, No. 2, pp.150-159, 2004,.
32. Coatanéa E., *Conceptual Modelling of Life Cycle Design*: *A Modelling and Evaluation Method Based on Analogies and Dimensionless Numbers*, PhD dissertation, ISBN 951-22-7853-7, ISBN 951-22-7852-9, 2005.
33. Choulier D., Forest J., Coatanéa E., *The engineering design CK theory: contributions and limits,*. 22nd International Conference on Design Theory and Methodology DTM, August 15-18, 2010, Montréal, Quebec, Canada
34. Schon D. A. (1983), *The reflective practitioner*, Arena, Ashgate publishing limited, GB.
35. Choulier D., *Towards a new theory for design activity reasoning*, 1st International Conference on Design Creativity, (ICDC2010), Kobe (Japan), November 29(Mon) - December 1(Wed), 2010.